CHAPTER 5 RADIOLOGICAL HEALTH SUPPORT OPERATIONS

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PART 1 EXTERNAL DOSIMETRY

511 Requirements

[In this Article, “dosimeter” or “primary dosimeter” refers to the dosimeter of record known as the personnel dosimeter monitoring badge, unless otherwise stated, to refer to supplemental dosimeters. The dosimeters of record are often called "TLD badges" or, due to past habits, "film badges".**]**

1. Personnel dosimetry shall be required for:

    a. Radiological workers who, under typical conditions, are likely to receive one or more of the following:

        (1) an effective dose equivalent to the whole body of 0.1 rem (0.001 sievert) or more in a year;

        (2) a shallow dose equivalent to the skin or to any extremity of 5 rem (0.05 sievert) or more in a year;

        (3) a lens of the eye dose equivalent of 1.5 rem (0.015 sievert) or more in a year; and/or

    b. Declared pregnant workers who are likely to receive from external sources a dose equivalent to the embryo/fetus in excess of 10 percent of the applicable limit stated in Table 2-1 (See Article 213).

    c. Occupationally exposed minors likely to receive a dose in excess of 50% of the applicable limit contained in Table 2-1 in a year from external sources.

    d. Members of the public entering a controlled area likely to receive a dose in excess of 50% of the appropriate limit in Article 212.3 in a year from external sources.

    e. Individuals entering a Radiation Area, High Radiation Area or Very High Radiation Area.

2. To maximize the efficiency of the personnel dosimetry program, the issuance of permanent dosimeters to personnel who are not radiological workers is discouraged.

3. Radiological Worker training is the minimum training necessary for those using a permanent dosimeter. Exceptions shall be made only with the approval of the RSO and written justification of the exception shall be provided to the Dosimetry Program Manager.

4. Personnel shall return dosimeters for processing as scheduled or upon request.

5. Personnel shall wear their primary dosimeters on the chest area, or between the waist and the neck, in the manner prescribed by the Radiological Control Organization. Compliance with this sub article will be encouraged by reinforcement during training sessions.

6. The practice of taking dosimeters off site is discouraged.

7. Personnel shall not wear dosimeters issued by Fermilab while being monitored at another radiological facility. Personnel shall not knowingly expose their dosimeters to security x-ray devices, excessive heat, or medical sources of radiation. If the potential for such exposures is discovered by personnel, the dosimeter should be returned to the ES&H Section with an explanation of the non-occupational source of exposure. Should such an exposure be discovered in the course of an exposure investigation or the examination of a suspect dosimetry report, the Dosimetry Program Manager shall notify the appropriate division/section personnel.

8. A person whose dosimeter is lost or damaged in a Radiological Area should place work in a safe condition, immediately exit the area and report the occurrence to the Radiation Safety Officer. Reentry of the person into radiological areas should not be made until a review has been conducted and line supervision has approved reentry with appropriate replacement dosimetry provided.

9. Technical details of personnel dosimeters in use at Fermilab are described in Appendix 5A.

512 Technical Requirements for External Dosimetry

1. Accreditation of personnel external dosimetry monitoring programs by the DOE Laboratory Accreditation Program (DOELAP) is mandated in 10 CFR 835. As Fermilab performs extremity monitoring on a discretionary basis, the dosimeter used for extremity monitoring is not subject to the requirements of DOELAP.

2. Fermilab participates with other DOE accelerator laboratories and other DOE facilities in intercomparison studies for external dosimetry programs.

3. In the absence of specific monitoring, the dose equivalent to the lens of the eye is taken to be equal to the dose equivalent at a tissue depth of 300 mg/cm^2.

4. Multiple dosimeters should be issued to personnel to assess whole body exposure in non-uniform radiation fields as recommended by the Radiological Control Organization or as required on Radiological Work Permits.

5. An exposure investigation (dose assessment) shall be performed for each instance of a lost, damaged or contaminated personnel dosimeter (See Article 572).

513 Pocket and Electronic Dosimeters

Pocket and electronic dosimeters are supplemental dosimeters that provide real-time indication of exposure to radiation. While they are not the dosimeter of record, such dosimeters can help to maintain worker doses ALARA, to indicate the presence of unanticipated radiological hazards, or provide a means of completing an exposure investigation in the event that a primary dosimeter is lost or damaged. Technical details of these devices are given in Appendix 5B.

1. Supplemental dosimeters shall be issued to personnel prior to entry into a radiological area in which a person's dose equivalent could exceed 40 mrem from external radiation in 1 workday, when entering a High or Very High Radiation Area, or when required by a Radiological Work Permit (RWP).

2. Supplemental dosimeters shall be worn close to the primary dosimeter and located in accordance with Article 511.5.

3. Use of electronic dosimeters is encouraged for entry into High Radiation Areas when planned dose equivalents greater than 100 mrem in 1 workday are expected. An electronic dosimeter provides an early warning of elevated exposure through the use of alarm set points at specified dose rates or integrated doses. The type used at Fermilab (Digi-Dose) alarms at specified intervals of integrated exposure. Such devices may not function properly in Very High Radiation Areas (See Article 333 for VHRA entry requirements).

4. An exposure investigation shall be initiated by the appropriate division/section personnel to explain certain discrepancies between pocket or electronic dosimeter readings and the primary dosimeter result (See Article 572).

PART 2 INTERNAL DOSIMETRY

521 Participation in Internal Dosimetry Program

1. In accordance with the requirements of 10 CFR 835 for monitoring individual exposures to internal radiation, internal dosimetry programs (including, but not limited to, bioassay programs) shall be conducted for:

    a. Radiological workers who, under typical conditions, are likely to receive a committed effective dose equivalent of 0.1 rem (0.001 sievert) or more in a year, from all occupational radionuclide intakes in a year.

    b. Declared pregnant workers likely to receive an intake or intakes resulting in a dose equivalent to the embryo/fetus in excess of 10 percent of the limit stated in Table 2-1.

c. Occupationally exposed minors who are likely to receive a dose in excess of 50 percent of the applicable limits stated at Table 2-1 from all radionuclide intakes in a year.

d. Members of the public entering a controlled area likely to receive a dose in excess of 50 percent of the limit in Article 212.3 from all radionuclide intakes in a year.

2. Radiation Physics Note #7, *Fermilab Internal Dosimetry Technical Basis Document,* documents for normal operations that no individual approaches the criteria defined above in paragraph (1) and thus, no routine internal dosimetry program is necessary. Fermilab may still perform discretionary internal monitoring when:

a. the Area Radiation Safety Officer requests such a measurement to verify the effectiveness of engineered and administrative controls designed to prevent internal exposure;

b. imposed engineered and/or administrative controls designed to prevent internal exposure inadvertently fail; or

c. someone is exposed under accidental or emergency conditions, in particular those requiring the use of the Decontamination or Beam-On Dose Assessment Facility.

3. Personnel shall participate in follow-up monitoring when their bioassay results or alternative assessment method indicate an uptake greater than the decision level.

522 Programmatic Requirements

1. Fermilab's internal dosimetry measurements are presently provided under an arrangement with Argonne National Laboratory. Argonne National Laboratory has been accredited by the Department of Energy Laboratory Accreditation Program for Radiobioassay. Should Argonne be unable to provide such services, Fermilab is committed to securing another DOELAP accredited vendor. Fermilab should maintain:

a. a current copy of the provider's DOELAP Accreditation Certificate;

b. information related to the calculation of decision levels and minimal detectable activities/concentrations for those radionuclides encountered at Fermilab; and

c. any other information that would aid in the interpretation of the results.

2. When it has been determined that internal monitoring is required, the Dosimetry Program Manager shall be notified to make the appropriate arrangements. The Dosimetry Program Manager is responsible for ensuring that samples are submitted in a timely manner, that bioassay results are obtained from the service provider, and that the results are promptly evaluated. This information should be documented in a logbook.

a. *In Vitro Samples*

(1) Argonne National Laboratory Radiochemistry Laboratory must be made aware of submittal of the samples, what radionuclide(s) are of interest, and informed that they are for special processing.

(2) Sample containers should be obtained from Argonne by the Dosimetry Program Manager and distributed to affected personnel through the Area RSO.

(3) Collection instructions are included with the sample containers. Instruct personnel to follow the directions explicitly. Collection times will vary depending on the type of sample. For urinalysis, a sample of approximately 1 liter is required over a 24 hour period.

(4) Collected samples should be delivered to the Dosimetry Program Manager with a Chain of Custody (RP Form #40).

(5) The Dosimetry Program Manager will arrange for a driver to deliver the samples to the Radiochemistry Laboratory to maintain the Chain-of-Custody.

(6) Results will be forwarded to the Dosimetry Program Manager upon completion of the analysis. Upon receipt of the monitoring results, the Dosimetry Program Manager will interpret the results and perform a dose assessment if the results indicate an uptake (see Article 523).

(7) If necessary, make arrangements for follow-up samples.

b. *Whole Body Count*

(1) Contact the Environment, Safety and Health Division at Argonne. Inform them that a person needs a whole body count and his/her estimated time of arrival. Identify the radionuclide(s) of interest.

(2) Arrangements need to be made with Argonne Security so that the person(s) can get to the whole body counter.

(3) Results should be forwarded to the Dosimetry Program Manager. Upon receipt of the monitoring results, the Dosimetry Program Manager will interpret the results and perform a dose assessment if the results indicate an uptake (see Article 523).

c. Emergency Situations

(1) If the monitoring is in response to an emergency situation, notification of the Dosimetry Program Manager should be made as soon as possible but no later than the end of the next working day.

(2) If sample containers are unavailable, use whatever may be convenient.

(3) Argonne should be told that the results are required on an emergency basis.

(4) Results should be forwarded to the Dosimetry Program Manager. Upon receipt of the monitoring results, the Dosimetry Program Manager will interpret the results and perform a dose assessment if the results indicate an uptake (see Article 523).

523 Dose Assessment

1. The estimation of internal dose shall be based on bioassay data rather than air concentration values unless bioassay data are:

   a. unavailable;

   b. inadequate;

   c. internal dose estimates based on representative air concentration values are demonstrated to be as or more accurate.

2. Interpretations of bioassay results and subsequent dose assessments will be documented and should include the following:

   a. Characteristics of the radionuclide(s), such as chemical and physical form.

   b. Initial and follow-up bioassay results and the person's previous exposure history to the extent known.

   c. Exposure information, such as the route of intake and time and duration of exposure.

   d. Biological models used for dosimetry of radionuclides.

e. Calculations used to estimate intake or deposition and to assess committed dose equivalent to any organ or tissue of concern and the committed effective dose equivalent.

Fermilab is committed to utilizing the methodology in ICRP 30 unless another model, i.e. MIRDOSE or ICRP 60, can be shown to be more appropriate.

3. Personnel shall be notified promptly of bioassay results and the results of any dose assessment.

4. The interpretations of bioassay results and subsequent dose assessments shall be incorporated into the affected individual's exposure history and maintained and reported according to the requirements in Chapter 7 of this Manual.

5. For exposures that could be mitigated though medical intervention, the Fermilab Medical Department shall be notified.

6. Exposures that exceed the Fermilab Administrative Goal for radiological workers or any of the limits stated in Part 1 of Chapter 2 of this Manual will be reported in accord with the requirements in FESHM 3010.

PART 3 RESPIRATORY PROTECTION PROGRAM

Respiratory protective devices include respirators with particulate or gas-filtering cartridges, supplied air respirators, self-contained breathing apparatus and airline supplied-air suits and hoods. The use of such respiratory equipment is governed by industrial hygiene considerations covered in Fermilab ES&H Manual Chapter 5103 which should also be consulted before the use of such equipment as the requirements of that chapter are only summarized here. Fermilab requirements for addressing heat stress hazards are given in detail in Fermilab ES&H Manual Chapter 5065.1.

531 Requirements

1. Use of respiratory protection should be reduced to the minimum practicable by implementing engineering controls and work practices to contain radioactivity at the source.

2. Respirators shall be issued only to personnel who are trained, fitted and medically qualified to wear the specific type of respirator. Training and fit testing shall be performed annually. Medical qualification testing shall be performed every two years.

3. Positive controls shall be maintained for the issue, use and return of respirators to ensure that only qualified personnel wear respirators.

4. Compressed air supplied to respirators shall be tested quarterly. Compressors shall be of the breathing air type and shall not allow oil or other chemicals and fumes to enter the breathing air supply. Special attention shall be focused on the location of compressor air supply intakes and on cross-connections to other compressed gas systems to prevent contamination.

5. Facility safety analyses should not take credit for the use of respiratory protection for routine work involving potential exposure to airborne radioactive materials. Engineering controls should be designed to control radioactive materials at the source, so that the use of respiratory protection can be reduced.

532 Half-Face Respirators

1. Half-face respirators shall not be used on a routine basis as a precautionary measure for protecting workers from potential airborne radioactive materials.

2. The use of half-face respirators may be permitted in situations where intakes of radioactive material are expected to be low and where industrial and safety considerations warrant, such as during the operation of heavy equipment.

PART 4 HANDLING RADIOLOGICALLY CONTAMINATED PERSONNEL

541 Skin Contamination

1. Survey techniques are described in Appendix 3C (Chapter 3) to determine the extent of skin contamination.

2. When personnel detect skin contamination, they shall call the Emergency phone number, ext. 3131. If injuries are also involved in a contamination incident, the medical treatment of injuries takes precedence over decontamination.

3. The extent of skin contamination should be determined prior to initiating decontamination procedures.

4. Skin decontamination procedures have been established at Fermilab. These are posted at the Decontamination Facility at 21 Shabbona for use by those individuals specifically trained to perform personnel decontaminations.

5. Levels of skin contamination that trigger the need for dose assessments should be established for site-specific radionuclides.

542 Exposures to Airborne Radioactivity

The most common form of airborne radioactivity at Fermilab is activated air. Activated air typically contains a variety of short-lived radionuclides which produce an external immersion hazard rather than an internal exposure hazard (see Articles 348 and 554). Airborne radioactive particulates are less common but may exist under special conditions, such as machining radioactive materials. If significant intakes of radioactive material are suspected, the following actions should be taken:

1. Identify personnel potentially exposed to airborne radioactivity.

2. Obtain nasal smears for qualitative indication of intakes, where appropriate.

3. Analyze air samples to determine airborne concentrations, where appropriate.

4. Determine duration of potential exposure to airborne radioactivity.

5. Perform bioassay appropriate for the type and quantity of radionuclides involved.

6. Use dose evaluation as soon as practicable to determine what actions, if any, are to be taken.

PART 5 RADIOLOGICAL MONITORING AND SURVEYS

Radiological Control Programs require the performance of radiation, airborne radioactivity and contamination surveys to determine existing conditions in a given location. Maps with sufficient detail to permit identification of original survey and sampling locations should be maintained. Records shall contain sufficient detail to be meaningful even after the originator is no longer available.

551 Requirements

1. Radiological monitoring of radiation exposure levels, contamination and airborne radioactivity shall be conducted to characterize workplace conditions and to identify areas requiring postings.

2. Monitoring shall be performed only by trained and qualified personnel using properly calibrated instruments which are appropriate for the type(s), levels and energies of the radiation(s) encountered and appropriate for the existing environmental conditions in which the instruments will be used.

3. Surveys for radiation, contamination and airborne radioactivity shall be performed as specified by the Radiological Control Organization or in Radiological Work Permits or other technical documents.

4. The Radiological Control Organization should review the adequacy of sampling and monitoring systems when facility or operational changes occur. Records shall be maintained to document changes in monitoring equipment, techniques and procedures.

5. Instruments used to perform radiation surveys shall be response-checked daily if in regular use or prior to operation if used intermittently. When response checks are not within ±20 percent of the expected value, the instrument should be taken out of service. When response checks are not feasible, such as with instruments used to measure neutrons or tritium, alternate methods should be established to ensure proper instrument performance.

6. Assessment of radiological conditions should include a sufficient number of survey points to characterize the radiation present and to verify boundaries.

7. Surveys should be performed before, during and at the completion of work that has the potential for causing changes in levels of radiation and radioactivity.

8. Survey frequencies should be established based on potential radiological conditions, probability of change in conditions and area occupancy factors.

9. Monitoring results should be reviewed by the cognizant radiological supervisor. The review should ensure that all required surveys have been performed and that the documentation is accurate and complete.

10. Radiological surveys should be recorded on appropriate standard forms and include the following common elements:

    a. Date, time and purpose of the survey.

    b. General and specific location of the survey.

    c. Name of the surveyor.

    d. Pertinent special information needed to interpret survey results (e.g., unusual background levels, special survey distances, etc.).

    e. Reference to a specific Radiological Work Permit if the survey is performed to support the permit.

11. Results of current surveys or survey maps should be conspicuously posted or made otherwise available to inform personnel of the radiological conditions.

12. Monitoring results should be made available to line management and used in support of pre- and post-job evaluations, ALARA preplanning, contamination control and management of radiological control operations.

13. Performance of radiation surveys should include dose rate measurements of the general area, dose rates at a distance of 30 centimeters from a source or surface of interest to evaluate potential whole body exposures, and dose rates on contact with potential sources of radiation where there is a potential for hands-on work.

14. Surveys should be conducted whenever operations are being performed that might result in personnel being exposed to small intense beams of radiation, such as those generated by shielded x-ray devices or due to removal or alteration of shielding.

15. Technical details of the portable survey instruments used at Fermilab to accomplish these objectives are summarized in Appendix 5C.

552 Area Radiation Monitors

1. In addition to the requirements of Article 551, area radiation monitors (not to include area monitoring dosimeters) should be installed in frequently occupied locations with the potential for unexpected increases in dose rates and in remote locations where there is a need for local indication of dose rates prior to personnel entering remote locations. Technical details of the stationary instruments used to monitor radiation fields at Fermilab are given in Appendix 5D which includes both routinely used instruments and specialty instruments developed for the accelerator radiation environment.

2. Area radiation monitors should not be substituted for radiation exposure surveys in characterizing a workplace. They may be used to characterize the radiation fields associated with accelerator/beamline operations.

3. The need and placement of area radiation monitors should be documented and assessed by the RSO when changes to facilities, systems or equipment occur.

4. Area radiation monitors shall be tested at least annually to verify audible alarm system operability and audibility under ambient working conditions and operability of visual alarms when so equipped and in circumstances in which the visible or audible alarm would actually be used.

5. If installed instrumentation is removed from service for maintenance or calibration, a radiation monitoring program providing at least equal detection capability should be maintained, consistent with the potential for unexpected increases in radiation dose rates.

6. The incorporation of area radiation monitors into a safety interlock system is described in Chapter 10 of this Manual.

553 Contamination Surveys

1. In addition to the requirements of Article 551, contamination surveys should be conducted in areas with the potential for the spread of contamination as follows:

   a. During initial entry into a known or suspected contamination area, periodically during work, at completion of job, or as specified in a Radiological Work Permit.

   b. After a leak or spill of contaminated materials or dispersible radioactive materials (e.g., dust, liquids).

2. Survey requirements for the release of materials are set forth in Articles 421 and 422.

3. Items with inaccessible surfaces which were located in known or suspected contamination areas and had the potential to become contaminated at levels likely to exceed Table 2-2 values should be treated as potentially contaminated and subject to administrative controls specified by the RSO unless the items are dismantled and monitored or special survey techniques are used to survey all surfaces.

4. Swipe surveys for removable contamination should be reported in units of disintegrations per minute per 100 cm^2 (dpm/100 cm^2). For swipe surveys of small items covering less than 100 cm^2, the results should be reported in units of dpm per area swiped.

5. Large area wipes may be used to supplement standard swipe techniques in areas generally assumed not to be contaminated, as specified by the RSO, in accelerator/beamline enclosures and at entrances to Contamination Areas. If an evaluation indicates that an area wiped is contaminated, a thorough contamination swipe survey should be performed.

6. In addition to the elements required by Article 551, records of surveys of removable contamination shall include, at a minimum, the following information:

   a. Model and serial number of counting equipment and calibration due date, if applicable.

   b. Contamination levels (using appropriate units) and appropriate supporting parameters including counting efficiency, counting time, correction factors, and type of radiation.

   c. Location of areas found to contain hot particles or high concentrations of localized contamination.

   d. Follow-up survey results for decontamination processes cross-referenced to the original survey.

554 Airborne Radioactivity Monitoring

1. Derived Air Concentrations (DAC) are listed in the appendices to 10 CFR 835. Unless otherwise specified, DAC will be taken to mean the DAC for a radiological worker throughout this Manual. The DACs listed in 10 CFR 835 Appendix A shall be used for environments containing airborne particulate radioactivity. The DACs listed in 10 CFR 835 Appendix C apply to immersion in semi-infinite clouds of radioactive gases, such as activated air, and may be modified to account for submersion in a cloud of finite dimensions.

2. Samples shall be taken as necessary to detect and evaluate the level or concentration of airborne radioactive material at work locations. Air sampling shall be performed where an individual is likely to receive an exposure of 40 or more DAC-hours in a year.

3. Air monitoring equipment should be used in situations where airborne radioactivity levels can fluctuate and early detection of airborne radioactivity could prevent or minimize inhalation of radioactivity by personnel. Selection of air monitoring equipment should be based on the specific job being monitored. Air monitoring equipment includes portable and fixed air sampling equipment and continuous air monitors. Pertinent technical features of accelerator-produced airborne radioactivity are described in Article 347.

4. Air sampling equipment should be positioned to measure air concentrations to which persons are exposed. If this cannot be achieved, a program of personal breathing-zone air sampling should be initiated.

5. Air monitoring equipment shall be routinely calibrated and maintained at a frequency of at least once per year. Continuous air monitors should be capable of measuring 1 DAC when averaged over 8 hours (8 DAC-hours) under laboratory conditions.

6. Real-time air monitoring equipment required by Article 554.2 shall have alarm capability and sufficient sensitivity to alert personnel if immediate action is necessary in order to minimize or terminate inhalation or immersion exposures.

7. In addition to the elements provided in Article 551, records of airborne radioactivity should include, at a minimum, the following information:

    a. Model and serial number of the sampler and laboratory counting instrument and calibration date if applicable; locations of fixed samplers may be used as identifiers where model and serial numbers are not available.

    b. Location of fixed air samplers.

    c. Location of portable air samplers used for a survey.

    d. Air concentrations in general airborne areas and breathing zones.

e. Supporting parameters, including collection efficiency, flow rate, duration of sampling, correction factors and filter medium.

8. A summary of technical information and procedures for using airborne particulate sampling equipment is given in Appendix 5E.

555 Characterization of Accelerator Radiation Fields

A variety of techniques and instrumentation has been developed to characterize accelerator radiation fields. The technical details of the devices used at Fermilab to do this are summarized in Appendix 5F. In some cases, these special devices and techniques are used in combination with other devices discussed elsewhere in this chapter and its appendices.

PART 6 INSTRUMENTATION AND CALIBRATION

561 Inspection, Calibration and Performance Tests

1. Calibrations shall use National Institute of Standards and Technology (NIST) traceable sources or other acceptable standards. This program is implemented at Fermilab by the ES&H Section's Instrumentation Team.

2. Calibration procedures have been developed by the ES&H Section for each instrument type and include frequency of calibration, precalibration requirements, primary calibration requirements, periodic performance test requirements, calibration record requirements and maintenance requirements.

3. Pocket and electronic dosimeters and area radiation monitors shall be calibrated at least annually.

4. Radiation instrumentation response to interfering ionizing and non-ionizing radiation and environmental conditions should be determined. The effects such interfering radiation has on an instrument shall be known prior to routine use by the general workforce.

5. Functional tests should be used to assess instrumentation designs that include alarms or that involve a process control. A functional test should be developed to test all components involved in an alarm or trip function and performed at least annually.

6. In unusual and limited situations it may be necessary to use an instrument in an application other than that envisioned by the manufacturer. Special calibrations should be performed for use of instrumentation outside manufacturer's specifications. The instrument should be adjusted, calibrated and labeled to identify the special conditions and used only under the special conditions for which it was calibrated.

7. Instruments should bear a label or tag with the date of calibration and the date the instrument is due for recalibration.

8. Instruments whose "as found" readings indicate that the instrument may have been used while out of calibration shall be reported to the Radiological Control Organization. The Radiological Control Organization should review surveys performed with the instrument while it was out of calibration.

9. Calibration records for fixed, portable and laboratory radiation measuring equipment and individual monitoring devices shall be maintained and include frequencies, method, dates, personnel, training and traceability of calibration sources to National Institute of Science and Technology or other acceptable standards.

10. Calibration records are maintained for the following equipment:

    a. Portable survey instruments.

    b. Laboratory, counting room and fixed radiation measuring equipment.

    c. Process and effluent monitors and sampling equipment.

    d. Radiation area monitors.

    e. Personnel contamination monitors.

    f. Pocket and electronic dosimeters.

    g. Air sampling equipment.

562 Maintenance

1. A program for preventive and corrective maintenance of radiological instrumentation has been established and documented.

2. Preventive and corrective maintenance should be performed using components and procedural recommendations at least as stringent as those specified by the manufacturer of the instrument.

3. Radiological instruments shall undergo calibration prior to use following any preventive or corrective maintenance or any adjustment that voids the previous calibration. A battery change is not normally considered maintenance.

4. Maintenance histories and calibration results for each instrument shall be created and retained. These records shall document the nature of any defects and corrective actions taken.

5. These records are maintained by the ES&H Section.

563 Calibration Facilities

1. Calibration facilities should perform inspections, calibrations, performance tests, calibration equipment selection and quality assurance in accordance with the recommendations of ANSI N323 and take the following actions:

    a. Locate activities in a manner which minimizes radiation exposure to operating personnel and to personnel in adjacent areas.

    b. Minimize sources of interference, such as backscatter and non-ionizing radiation, during the calibration of instrumentation and correct for interferences as necessary.

    c. Operate in accordance with the referenced standards.

    d. Generate records of calibration, functional tests and maintenance in accordance with the referenced standards.

2. Subcontracted calibration services should be performed in accordance with the referenced standards.

PART 7 EXPOSURE INVESTIGATIONS

571 Motivation

Fermilab is required by DOE to monitor occupational radiation exposures and to maintain dosimetry records as specified in 10 CFR 835. It is the intent of the Lab to maintain accurate, complete records of occupational radiation exposures for each person monitored (See Chapter 7). In most cases, this intent is satisfied by the dosimetry reports received from the dosimetry vendor. However, when gaps in the records occur (e.g., a badge is lost or damaged) or it is necessary to make adjustments to exposure records, an exposure investigation is performed to estimate the missing exposure, explain an anomalous reading, or document the reasons for the adjustment. The Exposure Investigation (EI) form it becomes part of the person's personal dosimetry file in order to maintain an accurate and complete radiation exposure history.

572 Circumstances Requiring an Exposure Investigation

When the Area RSO and the Dosimetry Program Manager concur that one of the following criteria are satisfied, an exposure investigation (EI) must be performed.

1. Missing exposure record. (Dosimeter is lost or damaged.) A dosimeter shall be declared lost if it has not been returned to the Dosimetry Program Manager within 45 days after the

end of the quarter for which it was assigned. The vendor provides notification when a badge cannot be processed because of damage.

2. Suspected inaccuracy in the exposure record.

3. Unexpected exposures.

4. Exposures to individuals on the ALERT list (See Article 214).

573 Guidelines For Completing Exposure Investigation (EI) Reports

1. The EI shall be completed as quickly as possible in order to obtain accurate information, which tends to be dependent on individuals' memories. Investigations shall be completed within 30 days of notification unless special circumstances make this impossible (See Article 573.9).

2. Division/Section personnel shall complete the forms for personnel affiliated with their organization.

3. If the investigation is for a reported whole body exposure which causes the annual deep dose to exceed 1500 mrem, a preliminary written report from the Dosimetry Program Manager shall be given to the SRSO within two working days.

4. Exposure investigations shall be documented on the Exposure Investigation Report (RP Form #3).

5. This form shall be completed in such a manner that it will be obvious to someone not familiar with the area or personnel that a complete investigation has been done and that the dose assignment is justified.

    a. Radiation surveys, measurements and/or calculations which support the assessment shall be attached.

    b. Personnel identification shall be included.

    c. Dosimeter information must always be included when available. When it is not available, the reason should be given.

    d. Similarly, information about co-workers is important and should be included.

6. A dose assignment is to be made by the investigator based on the Dose Assessment Section. It is necessary to obtain the signature of the badge holder or note that the badge holder is unavailable.

7. Subtractions from the legal exposure records will be made only after:

a. There is no reasonable explanation of how the dose could be real given the circumstances. The investigator is obligated to explain why the subtraction is being proposed.

b. The badge holder, if available, has indicated concurrence with the proposed subtraction by signing the EI.

c. The investigator has signed the EI.

d. The Dosimetry Program Manager concurs with the proposed subtraction by signing the EI.

8. Completed EIs shall be returned to the Dosimetry Program Manager. The completed EI is reviewed by the Dosimetry Program Manager and, if justified, changes to the permanent records made. EIs initiated through the ALERT system must also be reviewed by the Laboratory ALARA coordinator.

9. Exposure investigations should not be terminated until a conclusion is reached. However, in cases where the necessary information cannot be obtained, the Dosimetry Program Manager shall have the authority to terminate an exposure investigation. Efforts to contact individuals should be noted on or retained with the incomplete exposure investigation. Incomplete exposure investigations shall be retained in the wearer's exposure history file. The incomplete exposure investigation shall be sent to the Dosimetry Program Manager within 90 days after the end of the quarter for which the dosimeter was assigned.

10. Upon request of the division/section RSO or designee, the Dosimetry Program Manager can chose to remove personnel from dosimetry service until exposure investigations beyond 90 days can be completed.

Appendix 5A Radiation Dosimeters Used At Fermilab

Note: The monitoring devices listed below are designated as being beam-on or beam-off (in some cases both). A beam-off instrument may not be suitable for beam-on use due to excessive dead time or insensitivity to particles of interest. A beam-on instrument may not be suitable for beam-off use.

1. Comparison of Integrating Dosimeters

The following is a short comparison of some of the important characteristics of a number of passive integrating dosimeters in use at Fermilab and described in various sections of this chapter. Not all of these devices are suitable for use as personnel dosimeters. The principal ones used for personnel dosimetry are described below.

Dosimeter Type	Used to Measure	Lower Limit of Sensitivity	Upper Limit of Usefulness	Comments
TLD-100 (Natural mixture of Li isotopes)	γ-Rays and charged particles	5 mrad	100 krad	Very sensitive to thermal neutrons.
TLD-600 (^{6}LiF)	Fast neutrons using Bonner Spheres, and thermal neutrons when bare	3 mrem	60 krem	Used in 10" Bonner Sphere to measure typical accelerator spectrum outside thick shield. Very sensitive to thermal neutrons.
TLD-700 (^{7}LiF)	γ-Rays and charged particles	5 mrad	100 krad	Used in a TLD-600-700 pair inside a moderator (Bonner Sphere) to measure β–γ component.
Polycarbonate Track Etch	Fast neutrons a's	20 mrem	25 rem	1 MeV to 10-15 MeV
CR-39 Track Etch	Fast neutrons a's	20-30 mrem	25 rem	Useful energy range 150 keV to 10-15 MeV.
Elastic Polymer Bubble Detector	Fast neutrons	0.1 mrem	1 rem	0.1 MeV to 14 MeV. Also sensitive to thermal neutrons. Insensitive to γ-rays.
PIN Diode (Silicon)	Fast neutrons	2 rad	2 krad	Sensitive to neutron energies $\geq$ 0.2 MeV. Very low sensitivity to γ-rays. Not suitable for measuring personnel exposures
Foil Activation	High-energy hadron flux	10^{11} particles/cm^2 $\cong$ 10^5rads	10^{16} particles/cm^2 $\cong$ 10^{10} rads	Not suitable for measuring personnel exposures-See Appendix 5F

2. Personnel Dosimetry at Fermilab

The personal dosimeter of record currently in use at Fermilab consists of TLDs for gamma and charged particle detection, and track etch detector for neutrons. They are changed on the first working day of each calendar quarter.

Ring badges used to determine localized exposure to the fingers consist of a TLD.

a. Thermoluminescent Dosimeters (TLD'S)

Lithium fluoride (LiF) in the form of extruded ribbons cut in the shape of rectangles (^{7}Li-enriched LiF) is used to measure dose in the range from 5 mrads to 100,000 rads.

After exposure the dosimeters are read by heating the LiF and measuring the thermal luminescence, or light emitted, using a photomultiplier and picoammeter. Within certain limits, the amount of light emitted is proportional to the dose absorbed prior to heating. The dosimeters are prepared for reuse by annealing them (heating to high temperatures) to erase their "memory."

References:

1. "Thermoluminescent Dosimetry" - J.R. Cameron, N. Suntharalingam, and G.N. Kenney, University of Wisconsin Press, 1968.

2. "Thermoluminescence Dosimetry" - A.F. McKinlay Medical Physics Handbook 5, Adam Hilger Ltd. Publisher, 1981.

3. "Thermoluminescence and Thermoluminescent Dosimetry, Vols. 1-3," Yigal S. Horowitz, CRC Press, Inc., Boca Raton, Florida, 1984.

b. Track-Etch Neutron Dosimeters

The track etch neutron dosimeter is commercially available as a monomer allyl diglycol carbonate (trade name CR-39). The CR-39 dosimeter consists of a piece of the plastic in contact with a charged particle radiator made of polyethylene. Recoil protons from the radiator damage the CR-39. Both types of dosimeters are then chemically or electrochemically etched, making the ion tracks visible. The CR-39 is useful between 150 keV and 15 MeV.

The principal advantage of track etch neutron dosimeters is that they are not affected by moisture. The dosimeter badge used to measure gamma-ray exposure is paired with a track etch dosimeter to monitor neutron dose equivalent at Fermilab.

K. Becker, in Topics in Radiation Dosimetry, Suppl. 1, R. H. Attix, editor, Academic Press (1972).

B. J. Tymons, J. W. N. Tuyn, J. Baarli in Neutron Monitoring for Radiation Protection Purposes (Proc. Vienna Conf. 1973), IAEA, 1973.

M. Sohrabi, Health Physics 27 598 (1974).

W. P. Swanson and R. H. Thomas, in The Dosimetry of Ionizing Radiation, Vol. III, edited by K. R. Kase, B. E. Bjarngard and F. H. Attix (Academic Press, 1990).

Appendix 5B Supplemental Radiation Dosimeters Used At Fermilab

Note: The monitoring devices listed below are designated as being beam-on or beam-off (in some cases both). A beam-off instrument may not be suitable for beam-on use due to excessive dead time or insensitivity to particles of interest. A beam-on instrument may not be suitable for beam-off use.

1. **Pocket Dosimeters**: Primarily beam-off conditions—detects gamma rays and charged particles, integrating dosimeter. Small ion chamber. Must be recharged. Visual readout.

These are the cheapest, most common supplemental dosimeters and are designed for gamma and X-rays only. They are also useful for beam-on exposures outside thick shields when the radiation field is dominated by muons. They give questionable readings in neutron fields.

2. **Digi-Dose:** Small Geiger counter worn on belt for beam-off conditions. Primarily sensitive to gamma rays. Two versions are available. One has a mechanical register, while the other has a LED readout displaying the exposure in mR (milliroentgen). The former audibly alarms once per mR, while the latter can be set to alarm audibly either once per mR or 30-40 times per mR. Very useful for controlling exposure in High Radiation Areas. Should not be used as a survey instrument.

Appendix 5C Portable Radiation Survey Instruments Used At Fermilab

Note: The monitoring devices listed below are designated as being beam-on or beam-off (in some cases both). A beam-off instrument may not be suitable for beam-on use due to excessive dead time or insensitivity to particles of interest. A beam-on instrument may not be suitable for beam-off use.

1. **Geiger Counter:** Exposure rate meters, suitable for beam-off use only. Primarily sensitive to gamma and X-rays. The primary use is to check for residual activity and to measure exposure rates. The instrument consists of a portable box with a detachable probe. There are four major types:

Ludlum 14C-1: Side window, T-shaped energy compensated probe with minimal beta sensitivity. Ratemeter has 5 linear ranges.

LSM (Log Survey Meter) Side window T-shaped energy compensated probe with minimal beta sensitivity. Displays 3 decades on 1 range.

Bicron Surveyer 50: The instrument has a probe with an energy compensated housing. The housing provides a sliding beta-particle shield. It has a linear ratemeter with 3 ranges: 0-0.5, 0-5, and 0-50 mR/hr.

2. **Teletector/Extender 1000W**: A Geiger counter dose ratemeter suitable for beam-off use only. Detects gamma/X-rays and some charged particles. A very useful instrument in high radiation fields due to its high range capabilities and the relative isolation provided by its integral 4 meter collapsible probe extension. It resembles a fishing pole when fully extended.

3. **E140N**: A pulse ratemeter with associated 2 inch diameter thin end window Geiger counter probe. Beam-off use only. Detects charged particles and gamma/X-rays and is used primarily to detect low-levels of contamination. Average b-g sensitivity is 10%. Minimum detectable activity is about 0.3 nCi per wipe. The calibration for a typical Fermilab contamination sample is 200 cpm/nCi.

4. **Minimeter:** A miniature hand held dual-mode ratemeter with integral Geiger counter tubes. The CPM (counts per minute) mode utilizes a 2 inch diameter pancake tube for contamination detection. The mR/hr mode utilizes a small cylindrical energy compensated tube for dose rate measurements. This is a beam-off instrument only. The instrument includes a leather case with belt loop.

5. **Smart Ion**: A programmable multi-use ion chamber for beam-off use. Digital display shows dose rate (mR/hr) or integrated dose (mR). Simulated analog display shows dose rate trend or dose. A movable shield can be adjusted for beta/x-ray or gamma sensitivity. Ion chamber is also sensitive to neutrons. Alarms at set point. Scale changes

automatically when readings are outside of current range. The useful energy range for photons (±20%) is 10 keV to 1.3 MeV (shield open) or 22 KeV to 1.3 MeV (shield closed). Energy cutoff for betas is 70 keV (shield open) or 1 MeV (shield closed).

6. **Bicron Analyst:** A pulse ratemeter with single-channel analyzer calibrated as a count rate instrument (CPM), with associated NaI (Tl) scintillation probe, having a γ-ray response virtually identical to Thyac. For beam-off use only.

7. **Bicron Micro Rem:** A light weight, top-handle, box shaped ratemeter with 5 linear ranges measuring photon tissue dose rate from background levels to 200 mrem/hr. The detector is an internally mounted organic scintillator yielding a tissue equivalent response to gammas and X-rays from 40 keV to 1.2 MeV.

8. **Eberline RO-2:** Thin window air ionization chamber for beta, gamma, X-ray detection. Dose rate only; 4 linear ranges from 5-5000 mR/hr full scale. Specifically designed for flat response into the X-ray region; For beam-off use only.

9. **HPI 1010:** This instrument uses a tissue-equivalent proportional chamber to measure integrated absorbed dose (mrads) or dose rates (mrads per hour) when exposed to neutrons, gamma rays, and charged particles under either beam-on or beam-off conditions. It is delicate and should be handled with care. They are the most appropriate instruments for beam-on surveys, with integration being the preferred measurement technique. This instrument consists of an electronics box with top mounted handle and a front mounted detector.

10. **Snoopy:** A heavy, portable neutron counter consisting of an Anderson/Braun type moderated BF_3 counter connected to a ratemeter body. This instrument should be used only in low dose rate accelerator produced fields with long spill times to avoid saturation of the proportional counter. An Eberline ESP-2 supplies HV and all data measurement functions. It can be operated in either dose rate (mrem/hr) or integrate (mrem) modes. The ratemeter display should not be used. A scaler (with pulse shaper adaptor) should be attached to the AUDIO/SCALER connector and the pulses counted on the $X10^3$ range. Calibration is 7500 cts/mrem (AmBe response). For beam-on low dose rate neutron surveys.

Appendix 5D Stationary Radiation Instrumentation Used At Fermilab

Note: The monitoring devices listed below are designated as being beam-on or beam-off (in some cases both). A beam-off instrument may not be suitable for beam-on use due to excessive dead time or insensitivity to particles of interest. A beam-on instrument may not be suitable for beam-off use.

1. **Chipmunk:** The "standard" area monitor used in experimental areas. It is an AC powered beam-on or beam-off neutron, gamma ray and charged particle detector. The instrument consists of a tissue equivalent ion chamber mounted in a yellow box with a blue electronics/indicator box on top. The upper box contains visual and audible indicators (ratemeter, lights, alarm) to display dose rates and alarm levels. External signal connectors provide remote readout and interlock capability and a digital pulse train for dose integration (2.5 μrem/pulse). The quality factor may be set to values of 1, 2.5, 5, or 10. A built-in check source provides a background of about 0.6 mrem/hr on the quality factor 5 setting. Its portable analogs are the tissue equivalent survey meters (Appendix 5C).

2. **Scarecrow**: A high range version of the Chipmunk. The specifications are identical to those of the Chipmunk with the following exceptions: (1) the ion chamber enclosure is RED; (2) the quality factor is preset at 4; (3) background level from the check source is 100 mrem/hr (ratemeter zero); (4) the digital pulse train calibration is 25 μrem/pulse; and (5) the high level alarm is user adjustable.

3. **Hippo:** A very large detector consisting of a 55 gal. ion chamber and associated electrometer integrator. This instrument is used for detecting small amounts of accelerator-produced radiation far from the accelerator and experimental areas.

4. **Wallflower**: A wall mounted, AC powered, Geiger counter ratemeter used for beam-off gamma ray detection. The instrument consists of a blue box with detachable probe. The instrument is generally mounted at labyrinth or enclosure exits and is used to classify all radioactive material leaving beamline enclosures. The meter face displays an activity class rating that corresponds to labels found in the vicinity of the instrument. The instrument also contains a light display and an audible alarm which activates at approximately 2X background radiation. Its portable analog is the portable Geiger counter (Appendix 5C).

5. **Frisker**: An AC powered pulse ratemeter with detachable pancake type Geiger counter probe. It is normally used to check for low-levels of contamination on personnel and for radioactive material leaving enclosures. It possesses a presettable audible alarm level. It is similar in operation to the portable E140N and the Minimeter's cpm mode (Appendix 5C).

6. **Wipe Sample Counters**: An AC powered timer/scaler with internal bias supply to power a detachable GM probe (may be different manufacturers or configurations). There are two types in use at Fermilab: SRM 100 and Nuclear Scaler. The probe is generally attached to, or an integral part of, a single sample Manual drawer changer. It is normally used by ES&H field groups to count wipes for immediate results. The efficiency/sensitivity is comparable to the APC GM counter (Appendix 5E).

Appendix 5E Procedures And Equipment Used To Measure Radioactivity Samples And Airborne Radioactivity Concentrations

A. Airborne Radioactivity Sampling

Airborne radioactivity is of two main types: radioactive gases which are produced by the interaction of primary and secondary particles with the constituents of air, and radioactive particulates which can arise from contaminated objects. Very different techniques are used to measure these different forms of airborne activity.

1. Derived Air Concentrations

Occupational DACs are defined differently for concentrations of airborne radioactive particulate matter and for radioactive gases. The DACs for airborne particulates and immersion doses are given in 10 CFR 835 Appendices A and C, respectively. The former presents a hazard of inhaling and retaining radioactive material within the body. The latter results in an immersion dose from continuous non-shielded exposure in a semi-infinite atmospheric cloud and can be corrected for submersion in a cloud of finite dimensions. Airborne particulates might be encountered in the case of machining radioactive material, or the accidental volatilization of a target or other material by a particle beam. An immersion dose may be encountered in the case of activated air. Air activated by beam interactions typically contains ^{11}C, ^{13}N, ^{15}O and ^{41}Ar. Other radionuclides are often found in smaller concentrations.

Use R. P. Form 25 to record details of the sampling and counting procedures, and follow the steps outlined on the form to calculate the concentration of activity in the air.

Compare the calculated concentration with the Derived Air Concentrations (DAC) of the radionuclide involved, as given in 10 CFR 835 Appendix A to determine working restrictions, if any. The Activation Analysis Lab may be used to identify radionuclides, if necessary.

1) Determine the Lung Retention Class

The classes D, W, and Y have been established to describe the clearance of inhaled radionuclides from the lung. This classification refers to the approximate length of retention in the pulmonary region. Thus, the range of half-times for retention in the pulmonary region is less than 10 days for class D (days), from 10 to 100 days for class W (weeks), and greater than 100 days for class Y (years). Some of the radionuclides present as airborne radioactivity at Fermilab are listed below:

Radionuclide	Inhalation Class (Consideration given to chemical form)
H-3	Not Assigned
Be-7	Y
C-11	D
N-13	Not Assigned
O-15	Not Assigned
Ar-41	Not Assigned
Na-22	D
Mn-54	W
Co-60	Y
U-238	Y

2) Determine Fraction of DAC Present

For known mixtures, this is done by summing the ratios of the actual activity concentration and the DAC for each radionuclide known to be present.

$$DAC\ Fraction = \sum \frac{Actual\ Concentration}{DAC_{inhaled}} + \sum \frac{Actual\ Concentration}{DAC_{immersion}}$$

For unknown radionuclides, the most restrictive DAC for those isotopes not known to be absent shall be used.

NOTE: The values given in Appendix A of 10 CFR 835 for radon with its daughters assume 100% equilibrium has been achieved. To allow for an actual measured equilibrium concentration or a demonstrated equilibrium concentration, the values given should be increased by the ratio R where:

$$R = \frac{100\%}{Actual\%} \quad \text{or} \quad \frac{100\%}{Demonstrated\%}$$

If the summation yields a value greater than or equal to 0.1, the area is an Airborne Radioactivity Area and appropriate controls and postings must be applied.

2. Gas Sampling

Triton 955B/1055B: There are several gas monitoring systems at Fermilab which use these devices. There are various sources of error which can affect the operation of a flow through gas monitor: cigarette smoke, aerosols and ions, moisture, ambient gamma radiation, etc. Air is pumped first through a filter, then an electrostatic precipitator, and finally into an ionization chamber. The filter and electrostatic precipitator remove the

charged particulates found in smoke and aerosols. The precipitator also removes the ions in the air produced, for example, by a match. A desiccant should normally not be used, as this will remove most of the airborne tritium which is in the form of HTO. (One should, however, use a trap to catch any liquid which might be introduced into the air hose.) The ambient gamma background is measured by a duplicate sealed ion chamber whose current is subtracted electronically from that of the flow through chamber. These units are calibrated for gaseous tritium; correction factors must be applied to measure concentrations of other radioactive gases. The readout on Multiplexer (MUX) is 30 hz per full scale reading. Thus, the user must make note of which scale is chosen to get correct results.

Stack Monitor: Measures beta emitting radioactive gases by in-line monitoring of a continuously changing sample (prefiltered for particulates). The system consists of a Ludlum 177 ratemeter, an air pump, flow meter, and counting chamber. The counting chamber is a 1 gallon paint can with a 2" dia. thin-window pancake G-M detector monitoring the interior volume. These are generally used to monitor the emissions from vents in the ceilings of beam enclosures. The system can be connected to MUX via an internal pulse divider/driver circuit and BNC connector in the ratemeter module. The MUX readout is such that one MUX pulse represents 100 counts from the G-M detector.

3. Particulate Samplers

"**In Place Monitors" (Eberline AMS-3)**: Measures airborne radioactive beta emitting particles by counting deposits on an in-line air filter. A 2" dia. thin-window GM counter is used as the contamination detector with an identical detector used to compensate for γ background. Generally used in areas where depleted uranium is present. The system can be connected to MUX via an internal pulse divider/driver circuit and BNC connector.

Portable "Grab" Samplers: In order to detect radioactive particulates, there are several Staplex high volume ("grab") air samplers in use which have an air flow rate of up to 75 ft^3/minute, depending on the type of filter used. This in turn depends on the nature of the radioactivity being sought. Detecting particulates containing α-emitters requires a tight weave filter so the particulates will be trapped on the filter surface, while beta and gamma-emitting particulates are best detected using more porous filters which permit greater air flow. Regardless of which filter is used one must ensure that the trapping efficiency is known and is reproducible. The two filters used are as follows:

Staplex™ Type TFA41, 4" diameter: This filter is rated for a flow rate of 20-26 ft^3/minute (approximately). It is ashless and has a 95% collection efficiency for 1 micron particles. It is easily countable for α-particles, obtaining 70% count and penetration absorption of approximately 30%. It has good efficiency for industrial dusts and for particulate matter size 10 microns and under down to 0.01 micron. The sampler may be operated for approximately 1 hour without overheating.

Staplex™ Type TFAGF41 Glass Fiber, 4" diameter: This filter is rated for a flow rate of 20-26 ft^3/minute (approximately). The glass filters are especially recommended wherever gravimetric weighing analysis may be required because of their nonhygroscopic properties, i.e., they will maintain constant weight under wide-ranging conditions of ambient humidity. They have excellent loading characteristics for routine air monitoring and for specialized monitoring of solid pollutants, oil, and acid smokes, etc. They are particularly recommended where high efficiency collection of fine particles is required. They have higher particle capacity than cellulose filters. Their collection efficiency for particles as small as 0.3 microns is 99.98%.

In addition, there are two low volume samplers. One is suitable for taking continuous samples of up to 24 hours in length (at 2 ft^3/minute); the other is battery operated and timer programmable to 99 min at 5 ft^3/minute.

During Sampling:

Record the times when the sampler is turned on and off. The total time of operation must be known to calculate the airborne activity.

Observe and record the average flow rate, using the meter on the back of the sampler.

After Sampling:

Handle the filter as if it were known to be contaminated. Place the filter under a pancake probe or in a sample changer planchet (~2" diameter circle) and estimate the fraction of the total area of the filter that this section represents. Wait about 1/2 hour, if possible, to count it; this allows some natural airborne activity to decay.

B. Low-Level Wipe Counters (Automatic Sample Changers)

A shielded proportional counter with an automatic sample changing apparatus (Tennelec LB5100) is kept by Fermilab ES&H Section to count wipe test smears for alpha and beta activity. A backup system with a shielded GM counter (Tennelec APC) is kept for emergencies and to count highly contaminated samples.

The fundamental purpose of taking wipes is to determine contamination levels of specific objects or areas. The copy of the results from all wipes counted on these low-level counting systems are to be saved in binders for each area. This is a necessary part of documenting radiation safety at Fermilab.

Procedures:

1. Use a standard wipe. Number your wipes.

2. Identify the location the wipes were taken.

3. Put only one wipe in an envelope. Glassine envelopes should be used.

4. Count the wipes (up to 12 at a time) on a pancake detector before bringing them to 21 Shabbona. If the reading is greater than 5000 counts above background, segregate the "hot" wipes and determine the contamination level by counting them individually with a pancake detector. Recheck the remaining wipes; if OK proceed to step 5.

5. Place wipes (each in an envelope) in a plastic baggie and bring them to the Sample Receiving area at 21 Shabbona.

6. Fill out the Wipe Count Request Form (R.P. Form 43), attach the form to the baggie, and place the package in the appropriate bin in the cabinet.

7. Prior to counting, ES&H Section personnel will screen the wipes. Wipes exceeding 1000 CPM will be removed from the wipe package and counted on the APC (GM based) system, which produces a printout similar to the LB5100 printout described below.

8. Radiation Physics personnel will count the wipes and send the persons designated on the form a copy of the results. The system automatically prints out the following information (this may vary slightly with the particular counting group software):

    a. The date the count was performed.

    b. A location description (specifics are handwritten).

    c. Column headings.

    d. Wipes in the batch with 0 being a background reference count. The sequence number generally refers to the number written on the wipe by the requester (if they're in order).

    e. The total time the wipe was counted.

    f. Gross counts in both the Alpha and Beta/Gamma channels.

    g. An activity calculation for each of the channels selected. Background is taken prior to counting the wipes, and is automatically subtracted from each sample count.

h. A contamination message is printed if the wipe sample which has just been counted has levels of activity exceeding the Fermilab prescribed limits.

The activity calculation discussed in step g above is performed using efficiency/sensitivity factors determined for specific isotopes or for general accelerator wipes (a mixture of isotopes). These efficiencies and sensitivity factors are shown in Tables 5E-1 and 5E-2.

C. Procedures For Submission of Samples to the Activation Analysis Laboratory

In order to minimize the potential for sample cross contamination and to facilitate sample handling and analysis at the Activation Analysis Laboratory (AAL), the following guidelines shall be followed. Exceptions to these guidelines must be approved by the AAL supervisor before the samples in question are submitted to the AAL for analysis.

1. Samples submitted to the AAL for analysis must be delivered to 21 Shabbona. No samples will be accepted at the Low Level Counting Lab (the 14 Shabbona garage) or 14 Shabbona.

2. All samples submitted to the AAL for analysis must be accompanied by properly completed Chain of Custody (COC) and AAL work request forms. Ensure that all parties who need to know the analysis results are clearly indicated on the AAL work request form.

3. Any rush job must be cleared through the AAL supervisor. Otherwise the analysis will be performed in the order of receipt of the sample.

4. Each sample submitted to the AAL must have a unique FNAL identification number associated with it as directed in the ES&H Manual, Chapter 8010. This number must be clearly marked on the sample, the COC form, and the AAL work request.

5. Samples submitted for gamma ray analysis only or for gamma ray analysis and tritium analysis must be submitted in 125 or 250 ml sealed Nalgene plastic bottles or a sealed Petri dish. The preferred container is the 125 ml Nalgene bottle. These bottles should never be filled beyond the molding joint where the bottle neck is joined to the body. Overfilling the bottle introduces added errors in estimating sample volume and geometry.

6. Samples submitted for tritium analysis only may be submitted in any sealed container desired. Small glass containers are the recommended vessel as they reduce tritium migration into the container walls.

7. All integral solid samples, wipes, and filters should be contained in a sealed plastic bag to minimize the potential for cross contamination of samples.

8. All sample containers must be sealed and the outside thoroughly cleaned before they are taken into 21 Shabbona.

9. Personnel entering 21 Shabbona must ensure that they carry no contaminated material into 21 Shabbona. A Frisker is provided in the 21 Shabbona foyer.

10. Only qualified personnel are allowed to transfer or in any other way alter samples after they have entered 21 Shabbona.

11. All groups which submit samples to the AAL for analysis are responsible for their disposal after analysis is completed. Once an analysis report has been sent, the samples to which that report pertains will be placed in an area of 21 Shabbona set aside for return samples. The individual or group for which the analysis was performed should pick up those samples within 2 weeks unless other arrangements are made with the AAL supervisor in advance. When the samples are actually picked up, the person picking them up should ensure that the samples are signed back to him by an AAL technician on the COC form.

Table 5E-1 Tennelec LB5100 Sample Changer Counting Efficiency for Various Isotopes

6/13/91

Isotope	Total Efficiency (%)			Count Rate Sensitivity (CPM/nCi)		
	Gas Flow Prop. Counter		NaI Counter	Gas Flow Prop. Counter		NaI Counter
	Alpha	Beta/Gamma	Gamma	Alpha	Beta/Gamma	Gamma
C-14	-	10.5	-	-	230	-
Na-22	-	25.8	11.6	-	567	256
Cl-36	-	34.4	-	-	757	-
Mn-54	-	2.4	4.2	-	54	92
Fe-55	-	12.6	-	-	277	-
Co-57	-	4.4	5.1	-	97	112
Co-60	-	18.7	8.2	-	412	181
Sr-90	-	69.2	-	-	1523	-
Tc-99	-	18.0	-	-	396	-
Ru-106	-	40.0	2.2	-	879	-
Cs-137	-	26.4	3.4	-	582	75
Pb-210	-	45.4	-	-	999	-
Th-230	9.8	8.6	-	216	188	-
U-238 (dep)	9.3	44.7	0.8	204	983	17
Am-241	12.8	8.1	0.9	283	178	20
Accel Wipe	10.6	18.2	-	234	400	-

The above efficiencies are for sample isotopes uniformly deposited on a cloth wipe.

The efficiencies for a general accelerator wipe are obtained by calculation from a typical accelerator produced mix of Na-22, Mn-54, and Co-60, from aluminum, concrete, and steel. The accelerator alpha efficiency is calculated from the average alpha efficiency of the alpha emitting isotopes above, as alpha contaminants would be introduced in, and not created by, the accelerator.

Table 5E-2 Tennelec APC System Counting Efficiency for Various Isotopes

6/13/91

Isotope	Total Efficiency (%)	Sensitivity (CPM/nCi)
C-14	3.8	84
Na-22	14.9	327
Cl-36	20.2	444
Mn-54	0.3	7
Fe-55	0.2	3
Co-57	0.7	16
Co-60	9.5	209
Sr-90	40.5	891
Tc-99	9.2	203
Ru-106	24.3	534
Cs-137	15.2	334
Pb-210	25.9	571
U-238 (dep)	24.2	533
Am-241	6.7	148
Accel Wipe	6	130

The above efficiencies are for sample isotopes uniformly deposited on a cloth wipe.

The efficiencies for a general accelerator wipe were obtained by intercomparison with the Tennelec LB5100 gas flow proportional counter.

Appendix 5F Special Instrumentation And Techniques Used At Fermilab To Characterize Accelerator Radiation Fields

1. Hadron Flux Measurements by Foil Activation

Foil activations are made to calibrate beam intensity monitors such as secondary emission monitors (SEMs), to measure gross high-energy hadron (strongly interacting particles such as neutrons, protons, pions, etc.) flux near targets and loss points, and to reconstruct energy distributions for hadron fields.

A lithium-drifted or high purity germanium gamma ray detector is used to resolve ^{24}Na and ^{52}Mn gamma rays from the multitude of radiations emitted by a natural copper foil irradiated with high-energy hadrons. These isotopes have half-lives of 15 hours and 5.7 days, respectively, and have high effective thresholds: approximately 600 MeV for ^{24}Na and approximately 70 MeV for ^{52}Mn. The threshold for ^{24}Na is similar to that for ^{149}Tb from gold, a reaction used for similar measurements in other laboratories, and the longer half-life of ^{24}Na compared with 4 hours for ^{149}Tb makes ^{24}Na much more convenient to use. ^{52}Mn acts as a back-up for ^{24}Na in cases where the foil cannot be removed within a half-life or so of irradiation.

For precision beam intensity measurements, a copper foil three inches in diameter and 0.005 inch thick is usually irradiated with 0.0007 inch thick copper “catcher” foils on either side to replace recoils leaving the foil. About one percent of ^{24}Na recoils leave the foil.

Other foils such as aluminum and polyethylene have been used when lower energy sensitivities are needed or when a broader energy response is desired. A summary of nuclear reactions typically used for these purposes is given in Table 5F-1. Note that 30 GeV cross sections are used where 300 or 400 GeV cross sections have not been measured. This should introduce no more than a 5% error.

Interference between gamma emissions nearly coincident in energy coming from different radionuclides in the same foil can introduce errors in quantification of the specific activities of those radionuclides if not properly accounted for. This interference can be detected and sometimes compensated for if a series of measurements are made over a period several times the longest half-life involved. Sometimes it is sufficient to count the sample very quickly after irradiation if a short-lived isotope is of interest, or to allow the short-lived isotopes to decay away if a longer-lived isotope is of interest.

Table 5F-1 Reactions Used for Foil Activation Measurements

Reaction	Cross Section (mb)	Half-life	Effective Threshold Energy (MeV)
$^{12}C(p,x)\ ^{7}Be$	9.2^{+}	53 d	30
$^{12}C(p,pn)\ ^{11}C$	24.6*	20 min	20
$^{27}Al(p,x)\ ^{18}F$	5.8**	110 min	40
$^{27}Al(p,x)\ ^{22}Na$	12.5^{+}	2.6 y	30
$^{27}Al(p,x)\ ^{24}Na$	8.4**	15 h	7
$^{63,65}Cu(p,x)\ ^{24}Na$	3.9**	15 h	600
$^{63,65}Cu(p,x)\ ^{52}Mn$	4.6**	5.7 d	70
$^{63,65}Cu(p,x)\ ^{54}Mn$	11**	310 d	80

$^{+}$30 GeV value
*300 GeV value
**400 GeV value

2. Bonner Spheres

Bonner Spheres, named after their originator T. Bonner, are polyethylene spheres of different diameters with holes drilled in them to allow a detector to be placed at each sphere center. Each size sphere has a different efficiency as a function of energy for detecting neutrons. An example of such response functions are provided in Fig. 1. The 18" diameter sphere is most sensitive to high-energy neutrons (3 to 100 MeV), while the 2" diameter sphere is most sensitive to low energy (thermal to 100 keV) neutrons. Using measurements made with a number of Bonner Spheres plus cadmium covered and bare detectors, one can extract a neutron spectrum or family of possible neutron spectra which could give the observed detector results. Frequently it is necessary to use only a few spheres in order to obtain useful information on the mean neutron energy, quality factor, and dose equivalent rate.

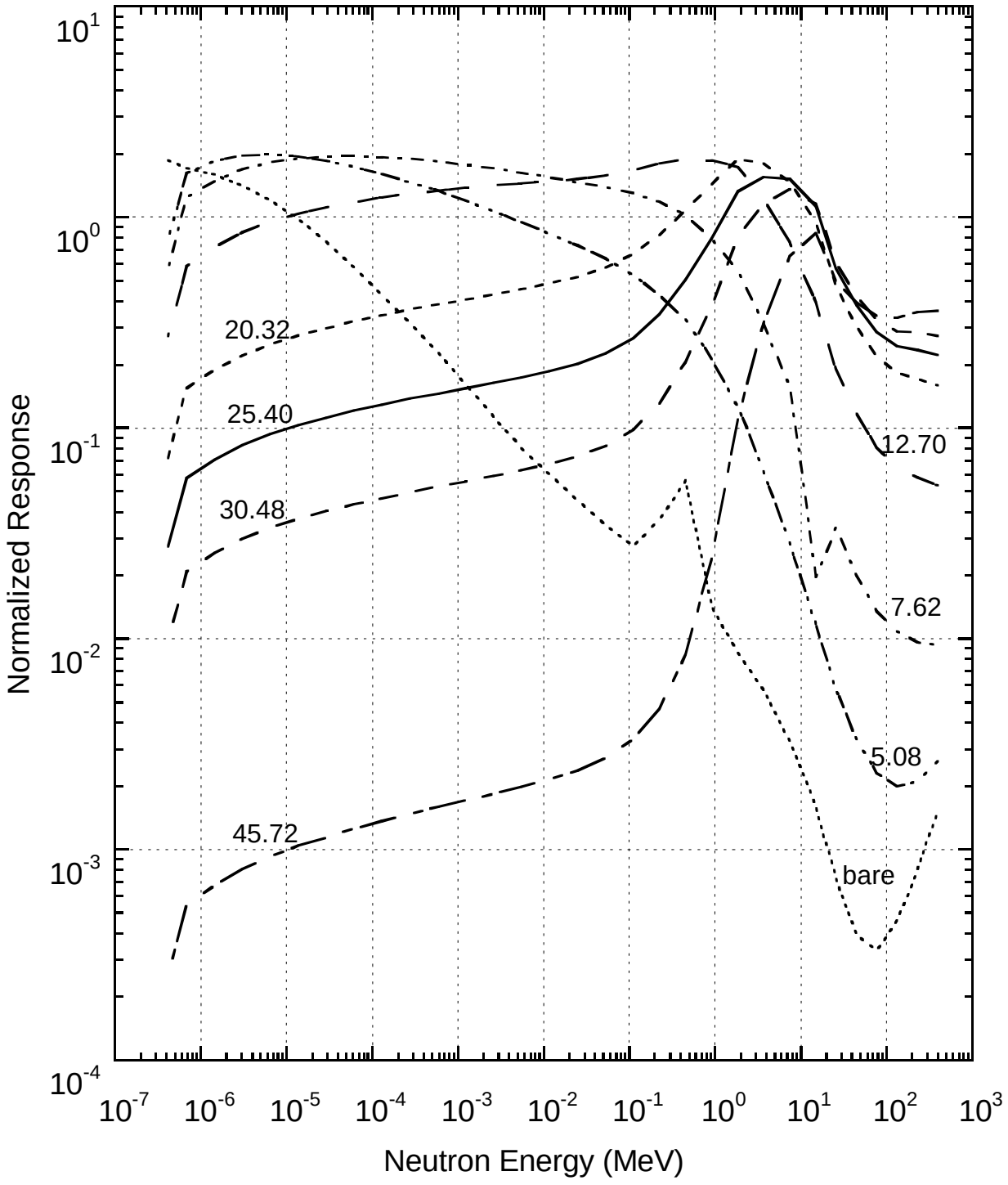

Figure 5-1 Efficiency of Different Sized Bonner Spheres for Detecting Neutrons, as a Function of Neutron Energy

Several types of detectors are used inside the Bonner Spheres at Fermilab. Lithium fluoride TLD's enriched in ^{6}Li or ^{7}Li are used to detect neutrons plus gamma, and gamma rays only. The difference between the two is proportional to the number of neutrons. Another detector used in Bonner Spheres is the LiI(Eu) scintillator enriched in ^{6}Li.

The addition of a plastic scintillator surrounding the LiI(Eu) enables the rejection of gamma rays and muons using pulse shape discrimination (Phoswich technique). A photomultiplier is coupled to both scintillators using a plastic light pipe. The signal from the plastic scintillator is fast (about 10 nanoseconds), while that from the LiI(Eu) is slow (a few microseconds). Pulses having a fast component are rejected. The short ranges of the alpha particle and triton from the reaction of a neutron with ^{6}Li plus the large energy released in the reaction (4.7 MeV) result in high acceptance of neutron-initiated events with excellent discrimination against gamma rays and muons. This technique is most useful in the larger spheres whose neutron detection efficiencies are so low that other background radiation can be a problem.

Bonner Spheres are relatively expensive to machine. A cheaper moderator is the polyethylene cylinder equal in volume to the 10 inch diameter Bonner Sphere. It has been used primarily with TLD's for studying neutron penetration of shields and neutron attenuation in labyrinths.

References

1. M. Awschalom, T. Borak, and H. Howe, "A Study of Moderators for a Neutron Dose Equivalent Rate Meter," TM-291 (1971).
2. R. C. Bramblett, R.I. Ewing, and T.W. Bonner, Nucl. Inst. Methods 9,1 (1960).
3. M. Awschalom and R. Sanna, Radiation Prot. Dosimetry 10, 89 (1985).

3. Precision Reproducible Long Counter (Neutron Detector)

The precision reproducible long counter developed by J. DePangher is used as the primary instrument for environmental fast neutron detection. The efficiency of the detector is constant (within 25 percent) up to a neutron energy of 10 MeV and then decreases rapidly. This makes the detector superior to others for measuring the number of fast neutrons below 10 MeV incident upon it. Another advantage of the long counter is its relative insensitivity to gamma rays; this results from the use of a BF_3 filled proportional counter to detect the neutrons (see below). However, to determine the energy spectrum of the incident neutrons, another technique such as spectrum unfolding using Bonner Spheres , is needed. A detailed description of the calibration of this detector is given in R.P. Note 26. A cross sectional view of the counter is shown in Fig. 2.

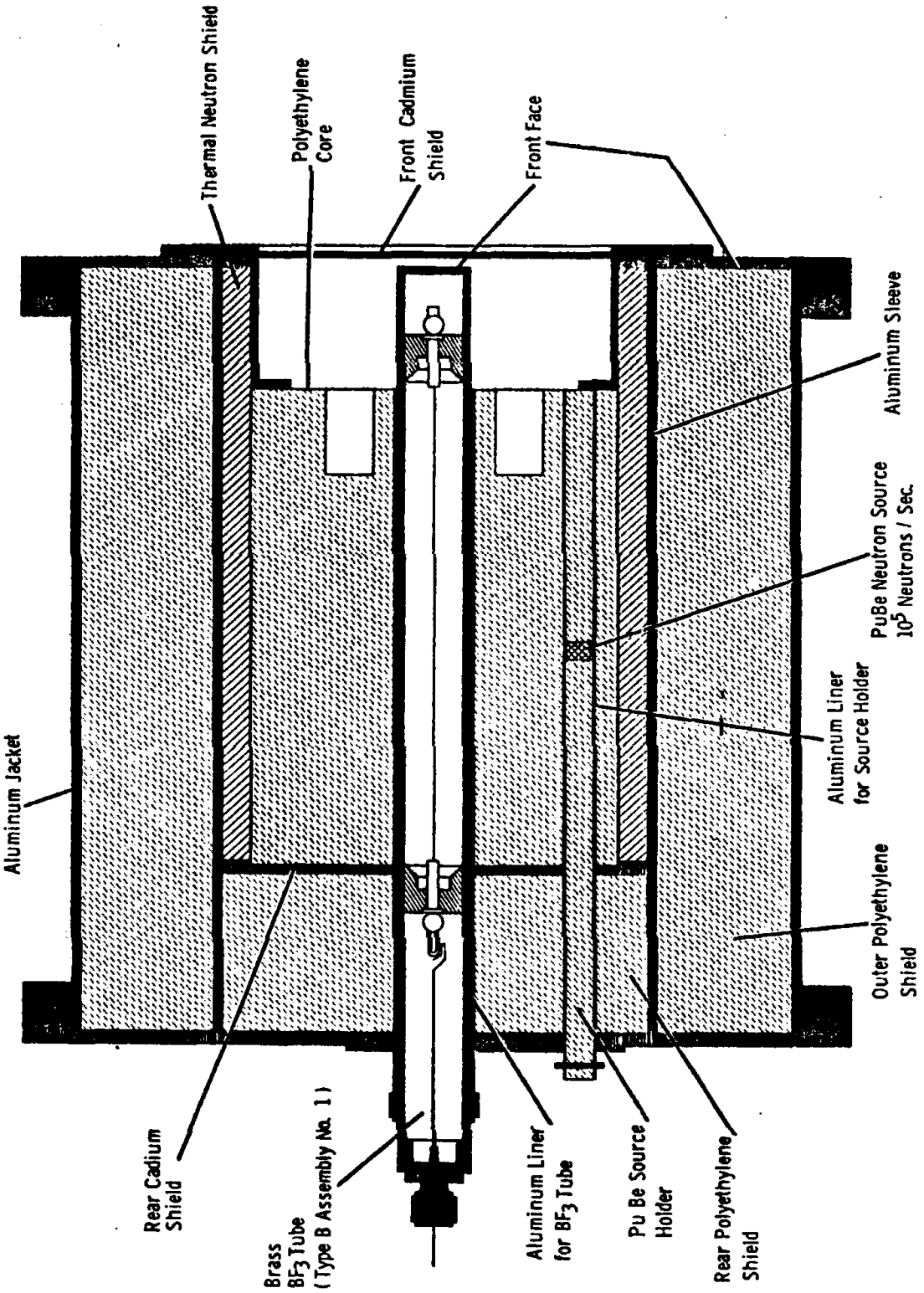

Figure 5-2 Cross Section of a Precision Reproducible Long Counter

Machined polyethylene is used to moderate (slow down) the fast neutrons. The first counters of this sort used paraffin as a moderator; using polyethylene instead makes the construction of these counters more uniform. Since the weight of a long counter is about 100 lb., they are periodically rotated about their longitudinal axes to reduce distortion of the polyethylene and thus maintain reproducibility. One long counter remains in storage at Site 68, and the other is located in the MERL (Mobile Environmental Radiation Laboratory).

Note in Fig. 2 that cadmium is used to reduce the number of thermal neutrons reaching the proportional counter from outside the long counter. A B_20_3 - impregnated (five percent boron) polyethylene thermal neutron shield with moderator outside (at larger radius) reduces the influence of fast neutrons scattered from the floor and walls near the counter.

The long counter is designed to give the most uniform response with energy for fast neutrons axially incident on its front face. To accomplish this, an annular region is cut out of the front of the central core to increase the counting rate for low energy neutrons.

The proportional counter is filled with BF_3 gas enriched to 96 percent in the isotope ^{10}B, which readily captures thermal neutrons to produce an alpha particle and a ^{7}Li nucleus sharing 2.3 MeV released in the reaction. This energy and the short-range of the particles produce a much larger electronic signal for a neutron than for a gamma ray interacting in the proportional counter. A discriminator is used to reject the smaller pulses produced by gamma rays.

4. Recombination Chamber

The recombination chamber is a device for directly measuring the average Linear Energy Transfer (LET) and thus the quality factor of a radiation field.

The LET of charged particles in a medium is the average energy loss of those particles per unit path length. The energy lost by the incident particles usually produces ionization in the medium. (In the case of uncharged incident particles, the relevant quantity is the LET of the secondary particles produced when the incident radiation interacts in the medium.) Different types of radiation (e.g., neutrons and gamma rays) often have different LET values. It is this difference in LET which is responsible for the different biological effects of equal doses of these types of radiation. The LET of a radiation field is used to determine the quality factor assigned to it; this quality factor reflects the ability of the field to produce harmful biological effects.

The recombination chamber uses the fact that "columnar recombination" losses in an ionization chamber (recombination losses along the paths of ionizing particles) depend on the average LET of the radiation field. The recombination losses are measured by the two identical ionization chambers in the unit. One chamber is operated at high potential (1200V) so that recombination losses are negligible. The other chamber is operated at such a low voltage (65V) that recombination losses are appreciable (~20%). The difference between the currents from the two identical ionization chambers is then directly dependent on the average LET of the radiation field, and thus on the quality factor of the field. An alternative mode of operation is to connect both

chambers in common and measure the anode current as a function of applied high voltage. This method works if a suitable normalization can be performed. In addition, to the ionization chamber itself, two power supplies and two electrometers are required for a measurement using the former technique while for the latter method only one electrometer and one power supply are required. A series of measurements usually requires between one hour and half a day. Its quality factor measurements are reproducible to perhaps 20%, and usually differ by no more than that amount from quality factor measurements made by other techniques.

Reference

1. J. D. Cossairt, D. W. Grobe, and M. A. Gerardi, "Measurements of Radiation Quality Factors Using a Recombination Chamber," FNAL TM-1248, 1984.

5. Muon Flux Detectors

There are two types of mobile systems in use at Fermilab which detect charged particles by using two scintillation counters in coincidence. The use of these systems outside a thick shield at small angles to the incident beam will in general result in the detection of muons, since the charged hadrons will be almost completely attenuated by the shield.

The larger system is mounted in the MERL (Mobile Environmental Radiation Laboratory) and is used mainly for monitoring the relatively low levels associated with off site radiation problems. The scintillators are 8" X 8" X 1/4" and are separated by a 10" X 10" X 1" aluminum plate. The normal single's background rate due to cosmic rays is approximately 400 counts per minute; this should be checked before starting a survey. For comparison, one would expect 1.7×10^5 counts per minute for a level of 1 mrem/hr if the counts were due to a muon flux entering perpendicular to the scintillators.

The smaller system is called a "muon finder." This detector and the associated electronics can be carried by one person. The LED scalers can be set to accumulate counts in one of four modes: coincidences between the two detectors, singles in either one of the two detectors, or random (i.e., delayed) in coincidences between the front and back detectors. The orientation of the telescope with respect to the muon direction is more of a factor here than for the MERL system, and a tripod can be used to help align it. The battery packs can last up to 5 hours (est.).

Characteristic of the small portable system is:

Scintillator Diameter	2.1 cm
Scintillator Area	3.6 cm^2
Scintillator Spacing	0.5 to 8.9 cm
Half-Angle of cone of Sensitivity	0.9 to 0.2 radian (51º to 11.5º)
Dose Calibration Factor* 1 mrem	90 muons
Dose Rate Calibration Factor* 1 mrem/hr	25 muons/sec

*Muon Flux assumed parallel to axis to instrument.